Leptogenesis from a GeV Seesaw without Mass Degeneracy

Can detectable sterile neutrinos do baryogenesis without mass degeneracy? Read more in [1].

The Cosmic Times

SEWM12 special edition - Wed 11th July 2012

New SUSY bailout - Despite fears of little hierarchy problems, theorists again increased the SUSY breaking scale to save the cMSSM from falsification. More on page 42.

A TESTABLE THEORY OF (ALMOST) EVERYTHING

Sterile neutrinos can explain all observed BSM particle physics.

The standard model of particle physics (SM) and theory of general relativity describe correctly almost all phenomena observed in Nature. Leaving aside accelerated cosmic expansion, only a handful of experimental facts definitely involve physics beyond the SM: neutrino oscillations, the dark matter (DM) density Ω_{DM} and the baryon asymmetry of the universe (BAU), responsible for today's remnant baryon density Ω_B. In [2] it has been suggested that all of them may be explained when the matter content of the SM is complemented by three right handed neutrinos with masses below the electroweak scale. Recently it has been confirmed that this can be indeed achieved and is consistent with all neutrino experiments, direct searches for sterile neutrinos, cosmology and BBN [3]. This possibility is realised within the νMSM, described by the Lagrangian

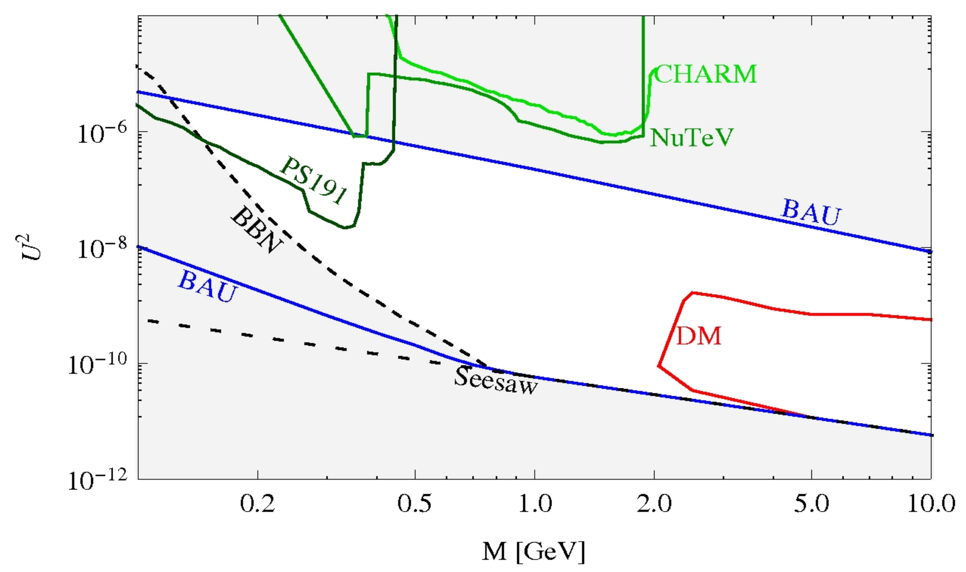
$$\mathcal{L}_{\nu MSM} = \mathcal{L}_{SM} + i\bar{\nu}_R \partial\!\!\!/ \nu_R - \bar{L}_L F \nu_R \tilde{\Phi} - \bar{\nu}_R F^\dagger L_L \tilde{\Phi}^\dagger - \frac{1}{2}(\bar{\nu^c_R} M_M \nu_R + \bar{\nu}_R M_M^\dagger \nu^c_R),$$

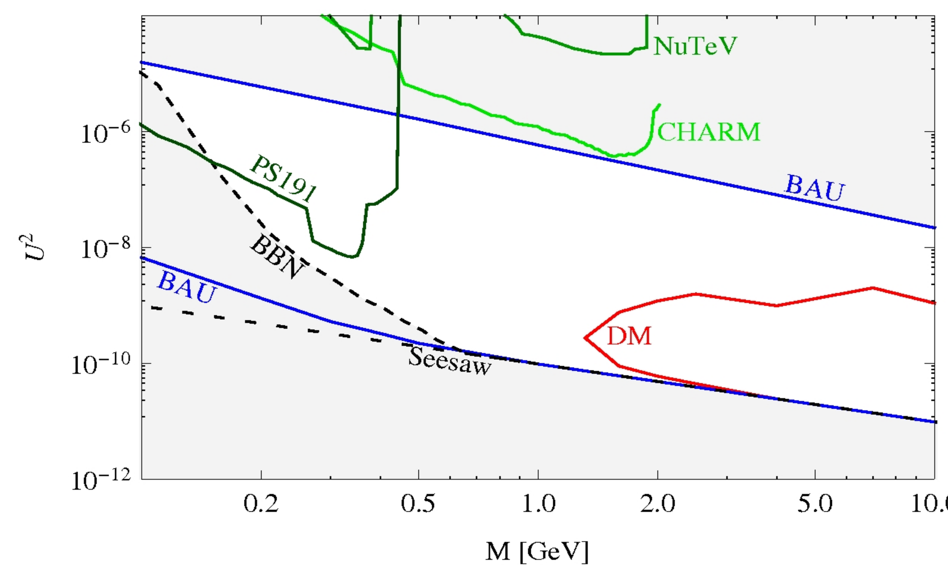
where F is a matrix of Yukawa couplings and M_M is a Majorana mass term for the right handed neutrinos ν_R. $L_L = (\nu_L, e_L)^T$ are the left handed lepton doublets in the SM and Φ is the Higgs doublet. In the νMSM, the eigenvalues of M_M are below the electroweak scale. This is required to simultaneously explain BAU and DM; at the same time, it avoids the "hierarchy problem" of the SM in the scale-invariant version of the νMSM [4]. There are two sterile neutrino mass eigenstates $N_{2,3}$ with quasi-degenerate masses $M_{2,3} \simeq M$ of a few GeV, which create the BAU during their production in the early universe [5] and generate active neutrino masses via the seesaw mechanism. The third sterile mass eigenstate N_1 has a mass $1 < M_1/\text{keV} < 50$ and is a DM candidate. The νMSM is motivated by the principle of minimality; in comparison with the SM, there is no modification of the gauge group, the number of fermion families remains unchanged and no new energy scale *above* the Fermi scale is introduced.

The sterile neutrinos $N_{2,3}$ may even be found experimentally, using upgrades to existing facilities.. For these searches, the most relevant quantities are the $N_{2,3}$ mass M and average mixing angle U^2 with active neutrinos. The figure below summarises all known constraints on these quantities.

- Below the black dashed "seesaw" line, the νMSM cannot reproduce the observed active neutrino masses and mixings.
- The green lines indicate upper bounds on U^2 from direct search experiments.
- Below the dashed black "BBN" line the $N_{2,3}$ produced in the early universe are long-lived and affect the abundances of light elements in the universe.
- In the region between the blue "BAU" lines, the νMSM can produce the observed Ω_B.
- Within the red line, $N_{2,3}$ can produce lepton asymmetries $|\mu_\alpha| > 8 \cdot 10^{-6}$ below the electroweak scale. This is necessary to make resonant N_1 production efficient enough to explain the observed Ω_{DM} [6].

The region in which all criteria are fulfilled is almost identical with the inside of the red line. To achieve this, the $N_{2,3}$ mass splitting has to equal the active neutrino mass splitting and one combination of mixing angles is essentially fixed to $\pi/2$. These tunings cannot be explained within the theory. However, the possibility to explain almost all signals of New Physics by right handed neutrinos alone makes the νMSM an attractive testable extension of the SM, and the predictions of the model (a Higgs boson with mass $m_H \gtrsim 125$ GeV [7], no other new particles at the LHC, no signals in direct DM searches) happen to be exactly what we currently observe. **More of this story in [3].**





Ockham back in business?

A comment.

The ancient Greeks believed that the laws of nature must be governed by aesthetic principles. For instance, the trajectories of celestial bodies were assumed to be perfect circles. In medieval Europe, scholars continued to fortify the prominent position of belief and aesthetics in philosophy, which remained widely unquestioned until the *scientific revolution* made empirical evidence the central criterion to judge a hypothesis.

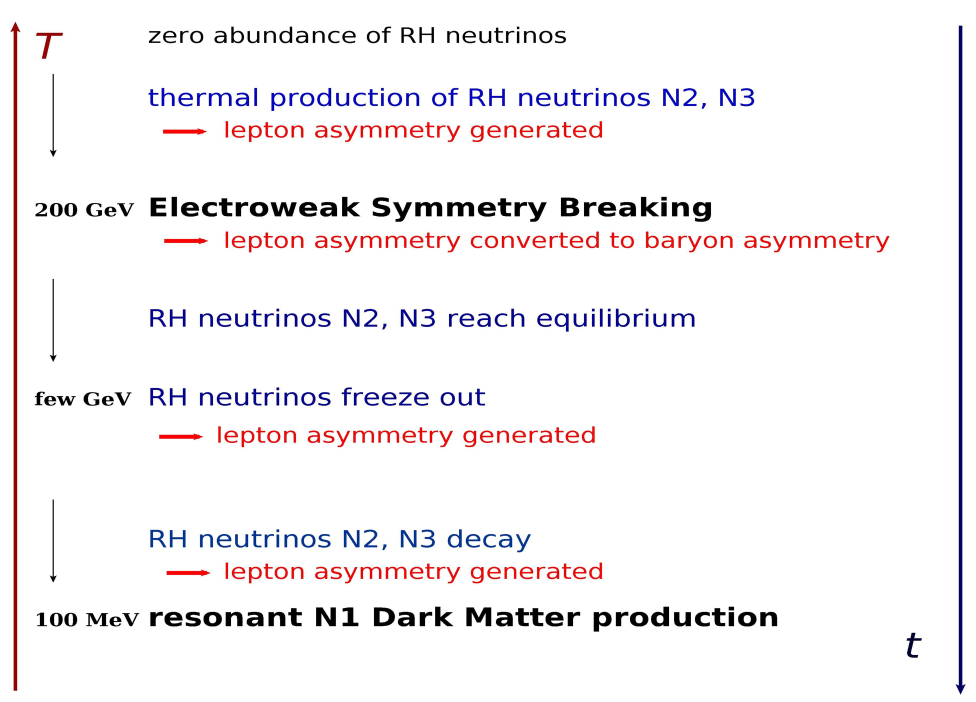
In recent years, particle physics has been lacking such evidence at the high energy frontier, leaving the nature of physics at and beyond the electroweak scale in the realm of speculations. Left with empty hands at the shore of the infinite dimensional space of theories, theorists had to resort again to guidelines of belief to explore the plethora of possibilities. There exist (at least) two conceptually different philosophies, which could be labeled *top down* and *bottom up*.

In the top down approach, arguments involving *naturalness* and aesthetic consideration are used to motivate new concepts/symmetries, such as GUT and SUSY, that govern physics at high energies. This approach certainly has its justification. However, to explain a small number of experimental deviations from the SM, one has to postulate the existence of a lot of new particles which in many cases cannot be found experimentally.

The bottom up approach is, on the other hand, motivated by the principle of minimality known as *Ockham's razor* [9]: Amongst two theories that explain a given dataset equally well, the minimal one, containing less parameters/concepts, is "better". A prominent example for this approach is the νMSM. Though the notion of "better" and "minimality"may be subjective to some degree, it is clear that the νMSM is an attractive candidate when applying Ockham's razor to the experimental situation in particle physics and cosmology.

In the past decades, top down approaches have received an enormous amount of attention. However, we observe no signals of the new physics predicted by the naturalness paradigm at the LHC [10], and DM searches provide no convincing evidence for the existence of WIMP particles, as predicted by SUSY. It is the main purpose of quantitative science to find explanations for observed phenomena, and not to fulfill aesthetic criteria, which may be subjective and time-dependent. Thus, it could be that we just witness a modern renaissance in physics, guided by Ockham's conviction *Frustra fit per plura quod potest fieri per pauciora..* - MaD.

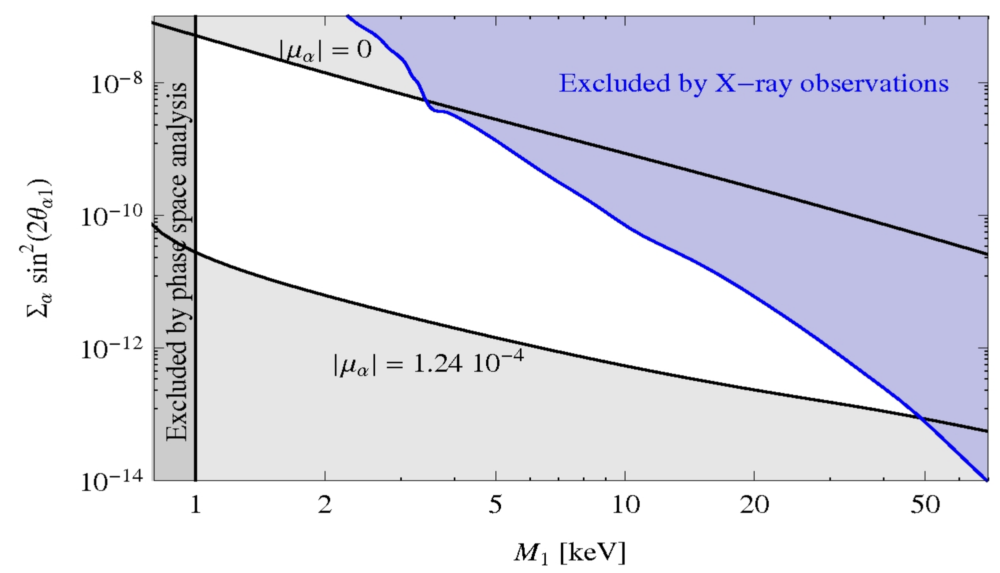
History rewritten



Thermal history of the universe in the νMSM

νMSM Sterile Neutrinos can be DM!

The current lack of signals in DM searches puts popular WIMP scenarios into question. Alternatively, DM could be composed of the lightest sterile neutrino N_1 in the νMSM [2,6]. N_1 are produced thermally in the early universe due to active-sterile mixing. In the absence of lepton asymmetries, $\mu_\alpha = 0$, the resulting spectrum corresponds to warm dark matter. For $\mu_\alpha \neq 0$ the N_1 dispersion relation in the primordial plasma is modified, which results in a resonantly amplified N_1 production [6]. This adds a non-thermal, colder component to the N_1 momentum distribution. X-ray observations, structure formation simulations and Ly$_\alpha$ forest data [8] suggest that the warm component alone cannot account for the observed Ω_{DM}. Then the presence of considerable lepton asymmetries, becomes a necessary condition for sterile neutrino DM production. It has recently been found in [3] that the required μ_α can be produced within the νMSM.



Further reading: [1] M. Drewes and B. Garbrecht, arXiv:1206.5537 [hep-ph]. [2] T. Asaka, S. Blanchet and M. Shaposhnikov, Phys. Lett. B **631** (2005) 151; T. Asaka and M. Shaposhnikov, Phys. Lett. B **620** (2005) 17. [3] L. Canetti, M. Drewes and M. Shaposhnikov, arXiv:1204.3902 [hep-ph]. [4] M. Shaposhnikov and D. Zenhausern, Phys. Lett. B **671**, 187 (2009); M. Shaposhnikov and D. Zenhausern, Phys. Lett. B **671**, 162 (2009). [5] E. K. Akhmedov, V. A. Rubakov and A. Y. .Smirnov, Phys. Rev. Lett. **81**, 1359 (1998). [6] M. Laine and M. Shaposhnikov, JCAP **0806**, 031 (2008). [7] M. Shaposhnikov and C. Wetterich, Phys. Lett. B **683** (2010) 196. [8] A. Boyarsky, J. Lesgourgues, O. Ruchayskiy and M. Viel, Phys. Rev. Lett. **102**, 201304 (2009); A. Boyarsky, J. Lesgourgues, O. Ruchayskiy and M. Viel, JCAP **0905**, 012 (2009). [9] William of Ockham, Summa Totius Logicae. [10] CERN seminars on 4th July 2012.